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Recommended Citation

Richard Campbell, Longwall Salvage Roof Fall Recovery Experience, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2015 Coal Operators' Conference, Mining Engineering, University of Wollongong, 18-20 February 2019
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LONGWALL SALVAGE ROOF FALL RECOVERY EXPERIENCE

Richard Campbell

ABSTRACT: Longwall (LW) salvage and relocation operations are a high-pressure period for all mine personnel, where any delays in the scheduled works are unacceptable, have a significant financial penalty and can increase mine worker's exposure to hazardous conditions. Successful longwall salvages rely on geotechnically controlled conditions, which allow for rapid shield recovery, often in dynamic environments. Recent longwall salvage at Mine A in Queensland experienced long operational delays, abnormal strata conditions, weighting events and shield convergence, culminating in a significant fall of ground outbye of the e-frame. This paper presents a case study of the geotechnical and operational conditions leading up to the fall of ground. In addition, some of the challenges faced and specific details of the fall recovery methods, successfully employed, are discussed, which allowed the safe and efficient resumption of salvage operations.

INTRODUCTION

Over many years, as the result of significant research and operational studies, numerous geotechnical roof support design methodologies have been developed for coal mine strata control. Each method, whether it's based on empirical, analytical and/or numerical methods, relies on understanding the geotechnical environment, applicability of the model and induced changes as a result of mining. As an industry progress in this field has been rapid and success is evident, with increasing design certainty and decreasing risk, hence it is possible to mine increasingly challenging deposits, safely and economically.

Longwall salvage situations however, remain an area where the risks are consistently present in terms of actual geotechnical understanding. These inherent risks affect the ability to design with absolute confidence and reduce the geotechnical control of the strata during salvage operations. Much of the geotechnical risk is actually due to logistical issues, such as time, equipment selection and ventilation. Past experience at the mine in question, or adjacent mines, remains the benchmark for "design". Longwall moves, being complex and unavoidable, are the least studied geotechnical challenges remaining in the industry. Perhaps the most concise summary and state of the art guideline for conventional recovery continues to be ACARP report C13022 by Hill (2006).

BACKGROUND, GEOTECHNICAL SETTING AND PREVIOUS EXPERIENCE

Mine A operates a set of 2 m wide shields in a 146 shield face, which are designed for mining a thick seam with a cutting height range of 3.0 to 5.2 m. Planned cut height for LW salvage is 3.8 m.

The geotechnical inputs for the LW salvage design called for 1280 t capacity shields, 320 bar (80 t/m²) set pressure, 380 bar high set pressure and 420 bar (100 t/m² yield pressure) and a tip to face of 650 mm while cutting a 1.0 m web. During this relocation all LW shields were scheduled to come out to the surface for major maintenance, including replacement of all leg cylinders and re-hosing.

Geotechnical setting

Depth of cover across Mine A ranges from 80 m, close to the pit bottom, to in excess of 400 m in the down dip northern extents of the lease. The experience base of LW salvages is within the 100 to 180 m range, with the fall of ground occurring at a depth of 165 m. The LW operates by extracting the lower 4.6 m of the seam, maintaining a 0.6 m - 1.0 m banded coal roof beam. The strata about the target seam is characterised by a moderate strength immediate siltstone/shale roof overlain by moderately bedded, stronger siltstone and sandstone units. Figure 1 shows the general stratigraphic column expected in the area of interest and the typical strata strength for the seam section.

Analysis of the numerous boreholes across the lease indicates an average Coal Mine Roof Rating (CMRR) of 32 within the coal roof and 52 for the overlying stone roof. Figure 2 depicts the range of CMRR values in the data set for the coal roof and stone roof environments. Based on a study conducted

by Mark and Molinda (2003), the coal roof can be classified as “Moderate to Weak” and the stone roof is classified as “Strong”.

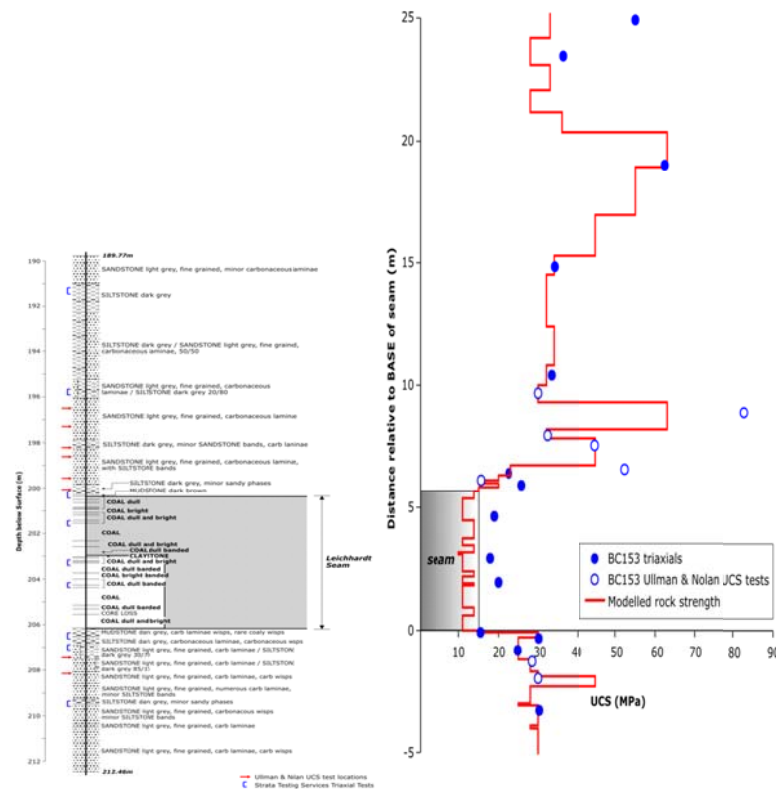


Figure 1: Typical stratigraphic column and strata strength profile

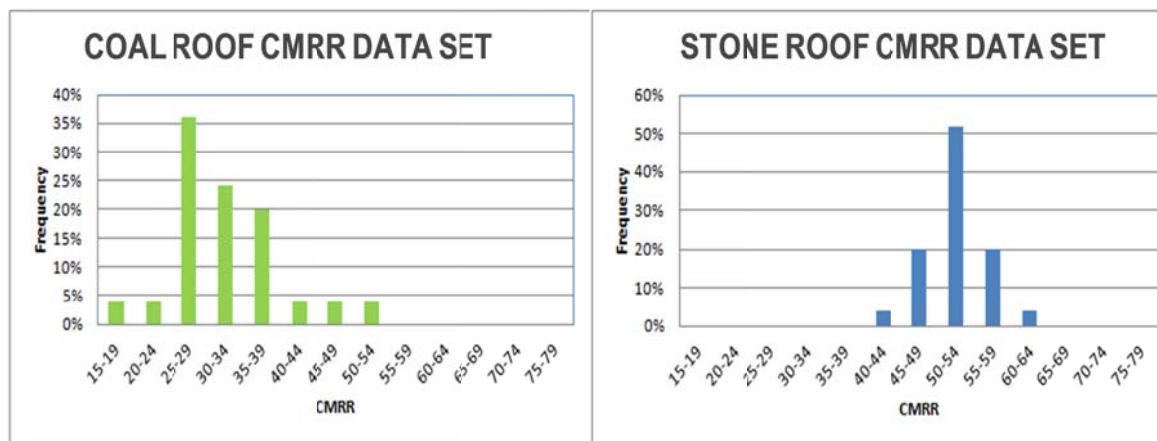


Figure 2: Summary of the CMRR data set

The target seam is heavily faulted with most LW blocks having full seam displacement structures, multiple fault zones and full seam displacement fault features being common place.

The roof strata are prone to periodic weighting cycles, typically at a 10 to 15 shear frequency. The common result of these frequent periodic weighting events, which are expressed as periods of rapid loading, and multiple yield events on shields in the affected zone, is an increased face spall and a roof gutter which runs parallel to the face – 600 mm wide and 500 mm high. Typically these events do not cause significant production issues. Figure 3 illustrates the typical time weighted average pressure TWAP & weighting events, loading rates and yield events leading up to the LW bolt up and salvage.

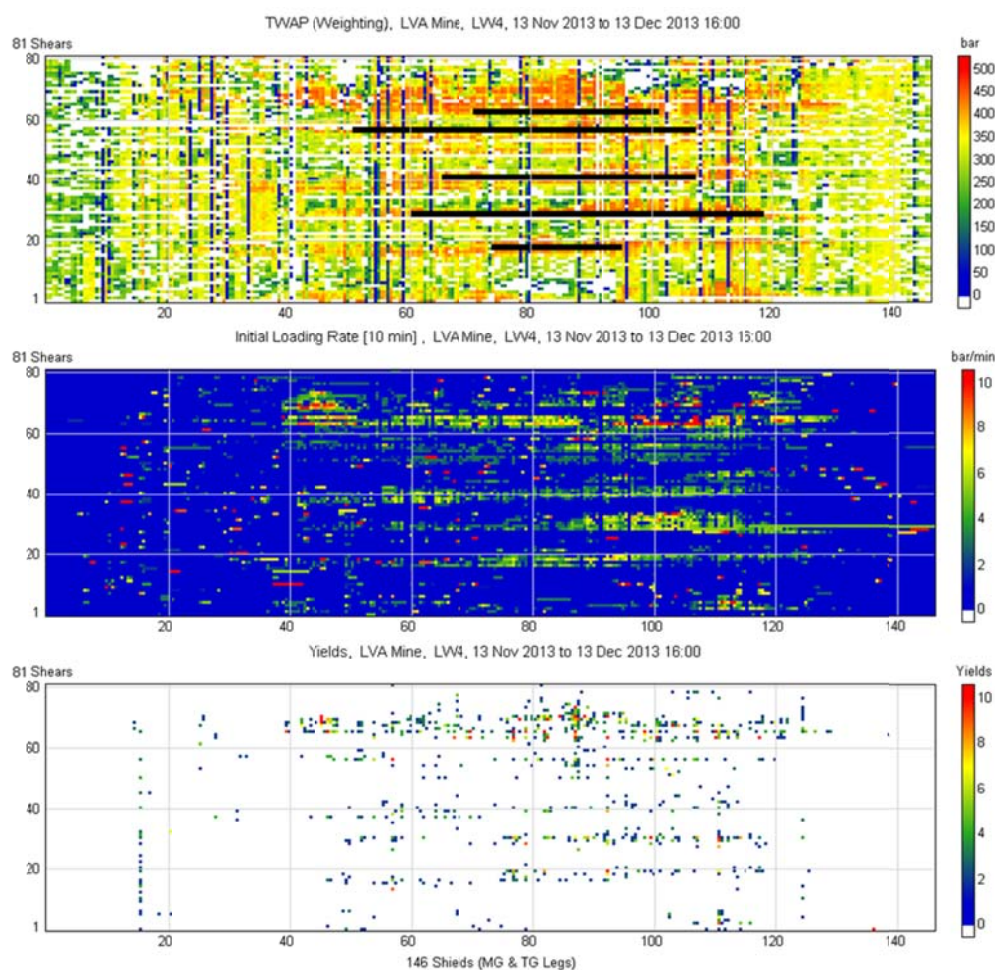


Figure 3: LVA data showing TWAP and weighting events, loading rates and yield events leading upto the LW bolt up and salvage

Previous experience

In the preceding six years the Mine A had undertaken five relatively successful and uneventful longwall relocations. Support plans and recovery strategies had been refined based on site experience, where a "leap-frog" shield recovery sequence was considered optimal, and the mine used a three shield E-frame. The tip to face for the forward shields was designed at 3 m, and 4 m for the back shields. The support strategy used bolts, 8 m cables and recovery mesh, with link'n'locks installed in place of each second shield, once removed, in normal conditions. A Trigger Action Response Plan (TARP) was in place for varying conditions during bolt up and shield recovery, including tell-tales and convergence monitoring. If conditions deteriorated, the salvage would convert to a sequential pulling sequence, with standing support in place of each shield recovered and rock-props used along the face side.

SEQUENCE OF EVENTS PRIOR TO THE FALL OF GROUND

The LW bolt up and salvage was scheduled to begin leading up to the Christmas period and be completed early in the New Year. Bolt up was completed using rapid face bolters. Shield recovery was from TG to MG with two chute roads in place for access and ventilation.

A time line for the LW salvage is detailed below:

- December 2nd - Mesh on
- December 12th - Bolt-up completed
- December 18th - TG shields removed
- December 23rd - Tear down completed
- December 23rd - Salvage of run of face shields started

- Shields 146 to 133 recovered
- December 24th to December 27th- operations stopped for Christmas break
- 27th December to 1st January - Salvage of shields 132 to 87 occurred as planned.
 - Convergence levels of 0-15 mm/24hrs recorded for shields, with the highest levels around mid-face. 200-300 mm total convergence recorded across the face
 - The goaf/roof behind the E-frame was noted as mostly standing from the E-frame to TG (approx. 124 m). This is not considered typical behaviour. Some sag noted on the face side.
 - Tell tales (not adjacent to shields being pulled) showing minimal or no movement
 - Other visual indicators showed no indication of abnormal deterioration
- 1st January - During the salvage of shield 86 significant convergence of shields 75 to 50 was noted (adjacent to the MG chute road), resulting in clearance issues for the dozer.
 - Shields 86 to 80 recovered
 - Convergence rates of 40 to 70 mm per 12 hrs recorded.
 - Total convergence of 700 mm in mid face region
 - Tell tales (not adjacent to shields being pulled) showing minimal or no movement
 - Other visual indicators showed no indication of abnormal deterioration
 - Some areas required the floor to be shot out to get clearance
- 2nd to 3rd January - Significant weighting event on shields 50 to 75.
 - Shields 79 to 77 recovered
 - Shields in yield between 50 to 75, convergence of 200-300 mm occurring in 24 hrs
 - Total convergence at mid face now 1000 to 1200 mm
 - Tell tales (not adjacent to shields being pulled) showed minimal movement
 - Goaf behind e-frame still standing, estimated to have sagged down to 1.5- 2 m off the floor.
- 4th January – At 3.30am, during the salvage of shield 76, a fall of ground occurred from shield 55 to the E-frame (40 m).
 - Shield 76 under the fall
 - Shields iron bound from 75 to 64
 - Goaf remained open from E-frame to TG – slowly getting closer to the floor from its initial height of 1.5-2 m at the time of the fall

The fall was limited from the tips of the forward shields to the face line (approx. 3 m – 4 m wide). The face line had crushed out significantly leading up to the fall. The height of the fall was estimated to be at least 8m (full length of cables visible and laser range finder used). Access and inspection of the fall was possible by traveling along the back of the remaining shields to the E-frame. Figures 4, 5 and 6 illustrate the extent of the fall.



Figure 4: Fall of ground from shield 55 looking towards the E-frame



Figure 5: Shield 76 under the fall – in the middle of the face road



Figure 6: View from the E-frame looking towards the MG

RECOVERY PLAN

Immediate actions taken

As with all falls of ground, the immediate concern is the safety of the surrounding environment. A detailed inspection was undertaken to define the areas of concern outbye of the fall and a stabilisation plan was implemented on the MG side of the fall, including the E-frame and adjacent shields. The main aim of this immediate stabilisation was to limit any further deterioration, provide a safe working place for the crews and allow a detailed recovery plan to be implemented. The inspection identified rapid deterioration of the roof and face from the fall outbye to around shield 27. Figure 7 illustrates the re-support installed outbye of the fall.

Immediate response included:

1. Standing rock-props along the face side from shield 25 to the lip of the fall to limit any shearing vertically along the block.

2. Install cable trusses from shield 25 inbye to the fall, with the cables angled well out over the face and the shield canopies.
3. Installation of 4m cables and dowels into the face side rib and also within the MG chute road, in order to strengthen the coal block.
4. Install monitoring devices down the length of the roadway and develop an inspection regime

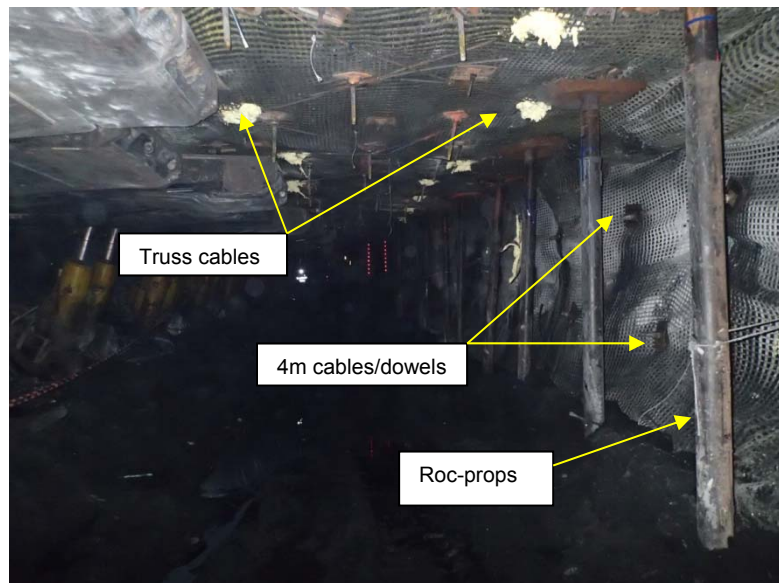


Figure 7: immediate response re-support outbye of the fall

Fall recovery plan

Immediately following the notification of the fall, the mine management formed an Incident Management Team (IMT) to ensure the correct risk based systems were followed and correct resourcing priorities were given to the fall.

The immediate task post-stabilisation was to gain an understanding of what the likely cause or causes of the fall were and define the mechanisms involved. This task was given priority, so as to give all stakeholders an understanding of the risks involved in the recovery of the remaining shields. The intended outcomes being:

- Gain an understanding of the cause of the fall in order to gain confidence in the recovery plan; and
- Determine whether a similar fall of ground was possible once salvage operations resumed.

A simple representation of the fall mechanism is depicted in the illustration below (Figure 8), where the mechanism described is very similar to that identified by Hill, D (2006) ACARP C13022.

Once the basic understanding of why the fall occurred was developed, a staged recovery plan was formulated with the underlying principal being;

- Provide a safe working environment, now and during salvage operations.
- The ability to resume LW salvage operations to recover all equipment.
- The final design had to be fit for purpose and allow normal salvage operations to recommence.
- No additional risks or impediments were to be introduced through remedial actions taken.

At this point in the operation many different strategies and ideas for how to go about the remediation works had been tabled; from the crews underground and adjacent mine sites, through to the head office staff - each strategy having its own merits and limitations. The IMT as a group worked to decide the actual stages to be taken based on the risk each task introduced. Each stage of the strategy was well-defined, quantifiable and included stop and go review points at the completion of each task so as to ensure the applicable design outcomes were achieved.

Each stage was subjected to a formal risk assessment and the workforce was kept up-to-date with regular briefings, including any changes to the plan going forward and revised completion dates. This regular forum gave each and every person the opportunity to raise any concerns.

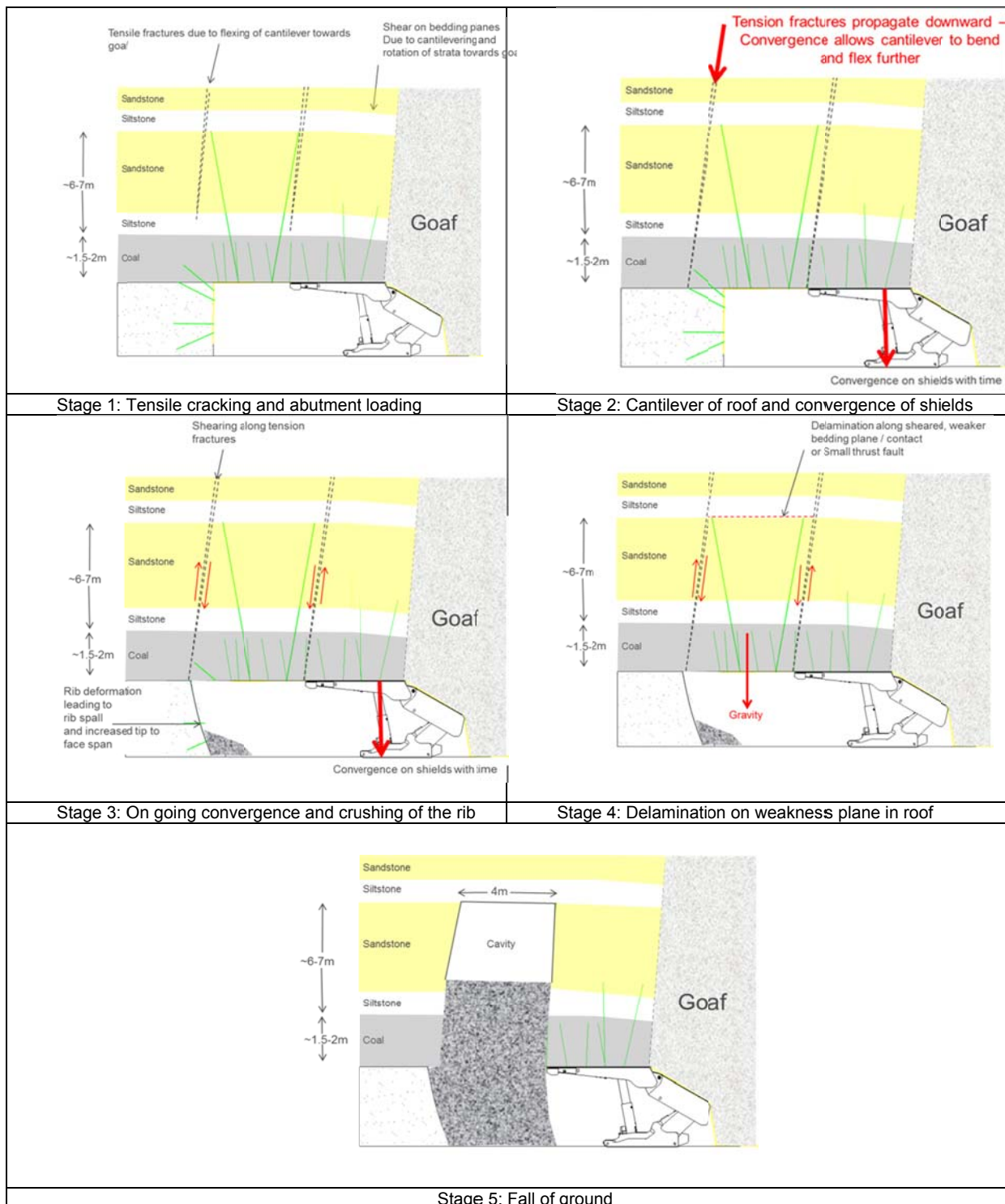


Figure 8: Failure mechanism and failure stages

The recovery plan was divided into five separate stages:

- 1) Place a “cocoon” of foam around Shield 78, as it would be encased in the planned back fill operations., This material had to be weak enough to allow Shield 78 to be pulled free when the time came.

- 2) Shutter off the fall area in preparation for backfilling with a weak grout mix. Drill proving holes and install stand pipes to ensure the grout fills the cavity above the fall (Figure 9).
- 3) Pump a weak cement fill material from the ground up, in stages to fill the void and consolidate the fall material.
- 4) Re-mine and re-support the tip to face zone from the MG side of the fall to the E-frame, using a road header – ensuring the excavated profile is fit for purpose for the resumption of shield salvage.
- 5) Resume salvage operations.



Figure 9: Shuttering off the fall material in preparation for consolidation of the muck pile and backfilling of the void in the roof

During the consolidation and back filling of the void above the fall a set of quality assurance tests were developed, aimed to ensure that the void above and adjacent to the face was effectively filled, the grout had cured as planned and to determine the condition of the rock mass above the canopies and over the coal face. A detailed programme of UG drilling and core sampling was undertaken to provide this information. As the results became available, they were reviewed and where necessary action was taken. Samples of the grout batches were also taken during pumping and sent to laboratories for strength and density testing.

The drilling confirmed that the muck pile was sufficiently consolidated and that the voids within the shutter and above the roof-line were filled. In addition, results showed that the rock mass above both the canopies and over the block was competent.

In conjunction with the pumping operations, and in preparation for the roadheader mobilisation into the panel, a series of discussions were held regarding the best method to re-support the roof and face as the roadheader re-mined the tip-to-face area. Two basic strategies were decided on as being worthy of investigating.

These being:

- Re-mine through consolidated fall material and stand steel sets, or
- Re-mine through consolidated fall material and install roof bolts and truss cables.

Both ideas were subjected to a design study and were tested in terms of; effective support capacity, safety during installation and subsequent shield recovery, and practicality during shield salvage. The workforce was involved in developing work methods for both options, which included risk assessments being undertaken for each.

The outcome was to re-mine and re-support the fall material using roof bolts and truss cables - this being the technically preferable option which had the least risk in terms of potential injury during installation as well as providing a higher actual support capacity. In addition, the installation of bolts and cables provided the best end result when salvage operations resumed. Steel sets would inherently be exposed to significant damage during the recovery of shields, where their structural integrity could come into

question. Once damaged or knocked out of alignment the support capacity is reduced and potentially they can collapse or become entangled with the shields. Potentially introducing a significant hazard to the operation.

A design and applicable support plan was developed for the installation of this support, which included, a monitoring system to provide adequate warning of any movement or further deterioration in conditions. Furthermore, a quality assurance program was initiated whereby a series of short encapsulation pull tests were undertaken in both the consolidated fall material as well as the in situ rock mass either side of the consolidated fall material, in order to quantify the actual support capacity that would be generated.

Re- mining and re-support

Once the method was finalised and the excavation geometry and support plans were issued, the roadheader began mining through the shutter. Re-mining took place from the 20th January and had completed mining onto the E-frame on 16th February, including the recovery of Shield 76 from within the consolidated muck pile. Figures 11 to 14 illustrate the re-mining process.

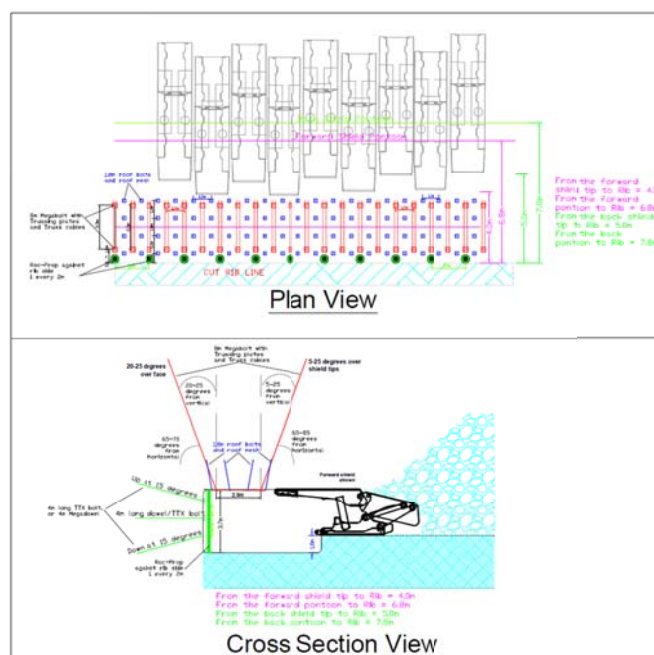


Figure 10: Support plan for re-mining through consolidated muck pile



Figure 11: Roadheader re-mining through the consolidated muck pile under the backfilled void



Figure 12: Consolidated muck pile and grout filled voids



Figure 13: Recovery of shield 76 from within the consolidated muck pile

RECOMMENCING LONGWALL SALVAGE OPERATIONS

Longwall salvage recommenced on the 18th February and was completed past the outbye edge of the fall on 22nd February. During this time there were no strata related delays, with minimal movement on tell tales installed through the consolidated fall material and no convergence recorded on non-ironbound shields. The goaf caved readily behind the E-frame as per normal conditions. All iron bound shields required the floor beneath the pontoons and bases to be shot fired, in order to provide some space to allow them to be pulled free. By the 28th February the last shields were taken off the face and the E-frame was disassembled.

LESSONS AND EXPERIENCE GAINED

Post recovery of the final remaining shields and prior to the resumption of LW operations in the adjacent block, several investigations and ICAM/Root Cause analyses were undertaken. The aim of these was to fully understand the root causes and future mitigation methods available, to avoid a repeat of the situation.

Areas assessed included:

- 1) The longwall move schedule and resourcing
- 2) Salvage equipment selection and availability
- 3) Geotechnical environment

- 4) Adequacy of the support plans, TARP's, monitoring and responses
- 5) Longwall system health
- 6) Delays in the salvage operations

Each aspect above was critically reviewed and evaluated, with the relevant outcomes documented in preparation for the next longwall salvage in order to avoid a reoccurrence.

CONCLUSIONS

Longwall salvages remain a time of elevated risk at every operation, where high pressure situations for all mine personnel are the norm. Conflicting resource demands and delays in the scheduled works has a significant financial penalty and can increase mine workers exposure to hazardous conditions.

Successful longwall salvages rely on geotechnically controlled conditions which allow for rapid shield recovery in often dynamic environments. There is currently a lack of engineering tools available to adequately assess the conditions, or address changes as they occur, and a general reliance on experience from within the mine or adjacent operations is often the primary design tool utilised.

This paper presents a case study of methods used to recover a significant fall of ground on a longwall salvage face. The case study provides an example of where a staged, risk based method was successfully developed and implemented. The importance of a collaborative approach, including a thorough quality assurance program, is thought to be fundamental to the success of any salvage operation and to ensure the resumption of normal operations is achieved.

ACKNOWLEDGEMENTS

The author wishes to thank the operation involved for permission to present the information within this paper. Their support has allowed for presentation of much of the above information previously to the Bowen Basin Underground Geotechnical Society and the Queensland Branch of the Australian Mine Managers Association. Their willingness to pass on learnings to the industry should be applauded. In addition the management team appreciates the work done during this recovery process, from the IMT to the operators of the grout pumps and the logistics support in the stores - everyone involved provided feedback, support, and a willingness to have a go in testing conditions.

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